CONTROL OF STORAGE-RELATED PHYSIOLOGICAL DISORDERS OF "D'ANJOU" PEARS BY INTEGRATED REDUCED DOSAGE OF ETHOXYQUIN AND LOW OXYGEN TREATMENTS[1]

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ABSTRACT

A 1000-p.p.m. ethoxyquin drench containing 528 p.p.m. thiobendazol (TBZ) fungicide prior to controlled atmosphere (CA) storage effectively controlled the development of superficial scald (SS) for 1 month regular air (RA) storage following 5 months CA storage. The preharvest drench was not effective in controlling the development of SS in fruit returned to RA storage following 7 months CA storage. Application of a 1750-p.p.m. ethoxyquin line spray (without TBZ) following 5 months CA storage effectively extended the control of SS to 2 months under RA conditions. The 1750 p.p.m. ethoxyquin line spray was effective in controlling SS for 1 month RA storage following an additional 2 months CA storage period. This represents a 36% reduction in the amount of ethoxyquin currently used on fruit stored for short periods of time. Minor, noncommercial amounts of pithy brown core (PBC) developed during storage, demonstrating that 1% O_2 and 1% CO_2 in a flow-through system can be safely utilized for the storage of pears. Growing location (Oregon vs. Washington) made no difference in the sensitivity to CO_2 injury and packing and handling damage.

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INTRODUCTION

The ultimate goal of commercial handling and storage practices for winter pears is to maintain pear fruits that are capable of ripening with good dessert quality without suffering any undesirable disorders throughout the marketing season, as well as to reduce the amount of cull fruit that develops during storage and transport (Hansen and Mellenthin 1979). Superficial scald (SS), pithy brown core (PBC) and skin black speck (SBS) are three major physiological disorders developing on/in PBC, and SBS are three major physiological disorders developing on/in "d'Anjou" fruit during the postharvest storage period. Manipulation of controlled atmosphere (CA) storage conditions is an effective, commercially viable control measure for SS of apple fruit (Little *et al.* 1982; Meheriuk 1994). Initial low-oxygen stress treatments followed by CA storage have been used on a semicommercial scale by the South African fruit industry to control SS on "Granny Smith" apples (Truter *et al.* 1994). Low O_2 CA storage combined with optimum CO_2 levels for "d'Anjou" pears may be an alternative to conventional chemical control of SS because 60% of "d'Anjou" fruit harvested in the Pacific Northwest each year are stored in CA. Currently, prestorage treatment with 2700 p.p.m. Ethoxyquin within 7 days after harvest is used to control SS of "d'Anjou" pears (Hansen and Mellenthin 1967).

Most CA studies on winter pears have been conducted in small research-sized chambers in Oregon and Washington over the past 10 years (Drake 1994; Chen and Varga 1997a,b; Chen 1999). A standard CA regime for storage of "d'Anjou" pears has been established as 2% oxygen and <1.0% carbon dioxide (Hansen and Mellenthin 1962, 1979; Hardenburg *et al.* 1986). CA storage with 1% oxygen plus <0.1% CO_2 prolonged the storage life and controlled SS of "d'Anjou" pears after 8–9 months of storage (Mellenthin *et al.* 1980). It is generally thought that elevated carbon dioxide (>1.0%) in CA storage could cause a brown core disorder of pear fruits (Hansen 1957; Hansen and Mellenthin 1962; Claypool 1973). However, Drake (1994) reported that "d'Anjou" pears stored in 1.5% oxygen plus 3% carbon dioxide under flow-through system conditions for 9 months were firmer, greener, and displayed less scald, internal breakdown and stem-end decay than pears stored in 1.5% oxygen plus 1% carbon dioxide. The economic advantage of holding CO_2 at higher levels can be significant because reducing CO_2 in CA storage to less than 1% is costly (Batsch *et al.* 1985; Welti and Cavalieri 1990). "D'Anjou" pears grown in Oregon and Washington may respond differently to the same CA environment because of the fact that the fruit have been exposed to different environmental conditions during growth and maturation. The objectives of this study were to:

(1) evaluate a preharvest drench of 1000 p.p.m. ethoxyquin for the control of SS disorder on "d'Anjou" pears following low oxygen CA storage; (2) verify the efficacy of low oxygen CA storage of "d'Anjou" pears for the simultaneous control of SS, PBC and SBS disorders on a commercial scale; (3) determine if there is a difference in CO_2 sensitivity between fruit grown in Oregon and Washington and (4) determine if a difference in sensitivity to packing and handling damage exists between fruit grown in Oregon and Washington.

METHODS AND MATERIALS

Fruit Source and Prestorage Treatment

"D'Anjou" pears at proper commercial maturity (65 N) were harvested in the Hood River, Oregon and Wenatchee, Washington areas (two bins from each of five growers). All fruit was commercially harvested within 2 days at each location and was delivered to Stemilt Growers, Wenatchee, WA for storage. Upon arrival, one bin of fruit from each grower was drenched with 1000 p.p.m. ethoxyquin solution containing 528 p.p.m. thiobendazol (TBZ) fungicide. The other bin of fruit from each grower was used as the control with no additional treatment. After treatment, the fruit was allowed to dry under ambient conditions and loaded into CA rooms.

Storage Conditions and Treatment

Fruit was cooled to -1 ± 0.5C within 5 days after loading the room. The flow-through CA room was then sealed, and oxygen and carbon dioxide in the room established at $1.0 \pm 0.1\%$ O_2 and $1.0 \pm 0.1\%$ CO_2 within 5 days. After 5 months of CA storage, the fruit was shipped to the Mid-Columbia Agricultural Research and Extension Center (MCAREC) in Hood River. Fruit in each bin was run separately through a packing line, and the incidence of cullage and rot determined. An additional dosage of 1750 p.p.m. ethoxyquin was applied to all fruit by line spray during the operation. Eight 44-lb cardboard boxes of fruit (box size 100–120, 18 kg/box) were randomly collected from each bin during the grading operation.

Four of the packed boxes of fruit from each bin were randomly selected and stored in regular air (RA) storage at -1 ± 0.8C for 30 or 60 days. The other four packed boxes of fruit from each bin were stored at -1 ± 0.5C in a regular CA room ($2 \pm 0.1\%$ O_2 and $1 \pm 0.1\%$ CO_2) at MCAREC for an additional 2 months. The CA-stored fruit was then returned to RA storage at -1 ± 0.8C and held for 30 or 60 days.

Poststorage Evaluation

After each storage interval, two packed boxes of fruit were ripened at 20C for 7 days. On day 1 of ripening, the incidence of SBS disorder, dark skin disorder (DSD), scuffing discoloration, and cullage and decay were determined. On day 7 of ripening, the incidence of SS, PBC, and additional cullage and decay were determined.

Defect Evaluation

Superficial scald (SS) and scuffing (SCF) were divided into four classes: (1) very slight = defect was detectable, but at such a low level as to not be considered to be a commercial defect; (2) slight = up to 25% of the fruit surface affected; (3) moderate = 25–50% of the fruit surface affected and (4) severe = more than 50% of the fruit surface affected. Pithy brown core (PBC) was likewise divided into four classes: (1) very slight = PBC was detectable, but at such a low level as to not be considered a commercial defect; (2) slight = one to two pits large enough to be considered a commercial defect, or one pit with very distinctive brown coloration; (3) moderate = two pits with distinctive browning and (4) severe = more than two pits. The commercial percentage of any of the defects equaled the total amount of slight, moderate, and severe defects. Indexes were developed to incorporate both frequency and severity of a defect into one number. Index = [(slight $\times$ 2) + (moderate $\times$ 4) + (severe $\times$ 6)].

Data Analysis

Data were analyzed as a completely randomized design with a split for location using the SAS general linear model procedure where the type III comparison-wise error rate was controlled (SAS 1999). Data are reported as least square means (lsmeans) with LSD mean separation.

RESULTS AND DISCUSSION

Skin Black Speck and Dark Skin Disorder

Neither SBS nor DSD were detected in any of the samples.

Scuffing

Treatment effects on scuffing are shown in Table 1. Overall, there was a significant increase in the percentage of slight and commercial scuffing in the fruit from Washington sources; however, it is only an increase in 0.4%, and is considered as minor. Prestorage ethoxyquin drench did not significantly

TABLE 1.
EFFECT OF LOCATION, PRESTORAGE DRENCH, STORAGE CONDITIONS AND MONTHS OF STORAGE ON THE DEVELOPMENT OF SCUFFING IN "D'ANJOU" PEARS

Location	Prestorage ethoxyquin drench	Months storage		Percent scuffing†				Percent Commercial Scuff	Scuff Index
		CA	Air	Very slight	Slight	Moderate	Severe		
OR	No	5	1	13.8 a	1.9 cd	<0.1 c	0.2 a	2.2 bc	5.4 bc
			2	7.2 bc	1.1 e	0.1 c	0.1 a	1.4 c	3.6 c
		7	1	2.8 de	0.1 e	<0.1 c	0.2 a	0.5 c	2.0 c
			2	0.2 e	0.2 e	0.1 c	0.2 a	0.6 c	2.4 c
	Yes	5	1	15.7 a	3.1 b	1.1 b	<0.1 a	4.3 ab	11.2 ab
			2	8.4 b	1.5 de	0.2 c	<0.1 a	1.8 bc	4.4 bc
		7	1	2.9 de	<0.1 e	0.2 c	0.2 a	0.5 c	2.2 c
			2	0.2 e	<0.1 e	0.2 c	0.1 a	0.4 c	1.6 c
WA	No	5	1	14.8 a	3.9 a	1.2 b	<0.1 a	5.2 a	13.2 a
			2	8.0 b	2.3 c	<0.1 c	<0.1 a	2.5 abc	5.6 abc
		7	1	2.6 e	<0.1 e	0.1 c	0.2 a	0.5 c	2.0 c
			2	0.3 e	0.1 e	<0.1 c	0.2 a	0.5 c	2.2 c
	Yes	5	1	7.8 b	2.3 c	2.1 a	0.1 a	3.5 ab	9.6 abc
			2	5.0 cd	1.6 de	0.2 c	<0.1 a	1.9 bc	4.6 bc
		7	1	1.6 e	<0.1 e	0.2 c	0.2 a	0.5 c	2.2 c
			2	0.1 e	0.1 e	0.2 c	0.2 a	0.6 c	2.4 c
Main effects – location									
OR	–	–	–	6.6 a	1.4 b	0.3 a	0.2 a	1.9 b	5.2 b
WA	–	–	–	5.2 a	1.8 a	0.4 a	0.3 a	2.5 a	7.0 a
Main effects – prestorage drench									
–	NO	–	–	6.4 a	1.6 a	0.3 a	0.2 a	2.1 a	5.6 a
–	Yes	–	–	5.4 a	1.6 a	0.2 a	0.3 a	2.1 a	5.8 a
Main effects – storage conditions									
–	–	5	1	13.0 a	2.8 a	2.1 b	0.2 a	5.1 a	15.2 a
–	–	5	2	7.1 b	1.6 b	0.2 b	0.3 a	2.1 b	5.8 b
–	–	7	1	2.4 c	0.2 c	0.3 b	0.3 a	0.8 c	3.4 c
–	–	7	2	0.2 d	0.2 c	0.2 b	0.2 a	0.6 c	2.4 c
Analysis of variance									
Location				ns	*	ns	ns	*	*
Drench				ns	ns	ns	ns	ns	ns
L × D				ns	ns	ns	ns	ns	ns
Storage				***	***	**	ns	***	***
L × S				ns	ns	ns	ns	ns	ns
D × S				ns	ns	ns	ns	ns	ns
L × D × S				*	**	ns	ns	**	**

*, **, *** Significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$, respectively.
† Means followed by the same letter within columns are not significantly different at $P = 0.05$.
ns, not significant.

affect scuffing. Storage conditions significantly affected the development of scuffing. Fruit stored in air for 2 months following the initial 5 month CA period had only about half the scuffing injury of fruit stored in air for only 1 month after the initial CA period. Storing the fruit for an additional 2 months in CA plus 1 month in air reduced the visible scuffing symptoms by almost 90% as compared with fruit stored for only 1 month in air following the initial CA period. This suggests that scuffing damage can be repaired given enough time after handling. However, the vast majority of the scuffing observed was barely detectable and may have been masked by the development of SS that was observed in greater amounts with longer storage times.

Over the years there has been the impression in the industry that scuffing is a more serious problem in fruit from Washington orchards than in fruit from Oregon. Thus Washington fruit is usually packed by late December or early January and stored in CA in packed boxes. The results of this study indicate that there is little danger to the Washington industry to extend their packing season to late February or early March This would give Washington shippers an additional 2 months of flexibility in their packaging options.

Superficial Scald

The effects of location, prestorage drench, and storage length and conditions on the development of SS are shown in Table 2. There was no significant difference in the percentages of SS in any category or scald index between the locations. Overall the 1000 p.p.m. ethoxyquin drench reduced the amount of SS in all categories. The percent commercial SS and scald index were both reduced by two-thirds with the prestorage application. The prestorage drench did not significantly affect the development of SS in fruit stored for 5 months in CA followed by 1 month in RA and 7 days ripening. However, if the fruit was stored for 2 months in RA following the initial CA period, the prestorage ethoxyquin drench significantly reduced the development of slight and moderate SS as well as the scald index. The 1000 p.p.m. prestorage ethoxyquin drench significantly reduced the incidence of SS in fruit stored for an additional 2 months in CA and then held in RA for either 1 or 2 months. The longer the fruit was in either CA or in RA following CA, the greater the incidence of SS.

The results of this experiment demonstrate that CA alone can adequately control SS for 5 months of CA, plus 1 month RA. The addition of a 1000-p.p.m. ethoxyquin drench prior to initial CA storage can extend the period of effective SS control to 5 months of CA plus 2 months of air storage, or 7 months of CA plus 1 month of air storage. These results demonstrate control for a significantly longer period than 3 months as been previously reported (Chen *et al.* 1999). Furthermore the fruit can be safely stored with a greatly reduced usage of ethoxyquin. Fruit stored for less than 5 months in CA and

TABLE 2.
EFFECT OF LOCATION, PRESTORAGE DRENCH, STORAGE CONDITIONS AND MONTHS OF STORAGE ON THE DEVELOPMENT OF SUPERFICIAL SCALD IN "D'ANJOU" PEARS

Location	Prestorage ethoxyquin drench	Months storage		Percent superficial scald†				Percent Commercial Scald	Scuff index
		CA	Air	Very slight	Slight	Moderate	Severe		
OR	No	5	1	4.9 d	1.4 f	0.2 e	0.1 d	1.7 c	4.2 e
			2	16.1 b	18.5 e	3.6 d	0.2 d	22.3 bc	52.6 d
		7	1	18.0 b	28.2 de	3.0 de	1.5 c	32.7 b	77.4 cd
			2	25.1 a	54.8 b	14.3 b	2.9 a	72.0 a	184.2 b
	Yes	5	1	0.2 d	0.2 f	0.2 e	0.2 d	0.6 c	2.4 e
			2	0.1 d	0.2 f	<0.1 e	0.2 d	0.5 c	2.0 e
		7	1	4.2 d	0.1 f	0.1 e	0.1 d	0.3 c	1.2 e
			2	10.1 c	41.8 c	1.1 e	<0.1 d	43.0 b	88.6 c
WA	No	5	1	7.5 c	3.1 f	1.2 e	0.1 d	4.4 c	11.6 e
			2	16.2 b	20.5 e	8.2 c	1.1 d	29.8 bc	80.4 cd
		7	1	16.6 b	31.1 d	2.7 de	0.2 d	34.0 b	74.2 cd
			2	7.3 c	65.6 a	18.7 a	2.2 b	86.5 a	219.2 a
	Yes	5	1	0.2 d	0.2 f	0.2 e	0.1 d	0.5 c	1.8 e
			2	2.0 d	1.5 f	<0.1 e	0.1 d	1.7 c	4.0 e
		7	1	5.1 d	3.0 f	0.1 e	0.1 d	3.3 c	7.6 e
			2	10.6 c	31.6 d	2.8 de	0.2 d	34.6 b	75.6 cd
Main effects – location									
OR	–	–	–	10.6 a	18.9 a	3.2 a	1.3 a	23.4 a	58.4 a
WA	–	–	–	8.3 a	19.7 a	4.6 a	1.2 a	25.5 a	65.0 a
Main effects – prestorage drench									
–	NO	–	–	14.0 a	27.9 a	6.6 a	1.5 a	36.0 a	91.2 a
–	Yes	–	–	4.9 b	10.6 b	1.2 b	0.3 b	12.1 b	27.8 b
Main effects – storage conditions									
–	–	5	1	3.6 c	1.7 c	1.1 c	0.4 c	3.2 c	10.2 b
–	–	5	2	8.9 b	10.4 b	3.4 b	0.3 c	14.1 b	36.2 b
–	–	7	1	12.0 ab	16.6 b	1.9 bc	1.9 bc	20.4 b	52.2 b
–	–	7	2	13.3 a	48.5 a	9.2 a	9.2 a	66.9 a	189.0 a
Analysis of variance									
Location				ns	ns	ns	ns	ns	ns
Drench				***	**	***	*	***	***
L × D				ns	ns	ns	ns	ns	ns
Storage				***	***	***	***	***	***
L × S				ns	ns	ns	ns	ns	ns
D × S				ns	**	***	***	***	***
L × D × S				ns	ns	ns	ns	ns	ns

*, **, *** significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$, respectively.
† Means followed by the same letter within a column are not significantly different at $P = 0.05$.
ns, not significant.

sold within 1 month of release from CA storage would need only an application of 1750 p.p.m. ethoxyquin, in comparison to the current practice of 2750 p.p.m., a 36% reduction in the amount of ethoxyquin used.

Pithy Brown Core

A very small amount of PBC was found in the fruit from growers in both Oregon and Washington, and was considered noncommercial in nature (data not shown). Although there is a significant drench–storage interaction on the PBC index, the relative lack of PBC in the storage overall indicates that the values are not horticulturally significant. There was a concern that PBC could be a problem in fruit stored for long periods under CA conditions of 1% O_2 and 1% CO_2, as had been shown in earlier in nonflow-through systems (Hansen and Mellenthin 1979). The results of this study indicate that "d'Anjou" pears can be safely stored under CA conditions of 1% O_2 and 1% CO_2 in flow-through rooms without a problem of PBC.

Rot and Other Cullage

The results of the treatments on the development of rot and decay during storage are shown in Table 3. No significant differences were noted in the cullage between locations or prestorage drench conditions. The main reasons for cullage were cork spot, stem punctures, codling moth and limb rub. Rot and decay, following the initial CA period was significantly greater in the fruit from Washington growers as compared with the fruit from Oregon growers. The fruit was selected by packing house representatives to meet the maturity standard (65 N) and be available on a specific date, and not to be necessarily from orchards which had followed the same preharvest pest and disease control programs. Storage rot and decay can be affected by many factors that occurred in the field prior to harvest. Thus, it cannot be concluded that Washington fruit is generally more prone to rot and decay than Oregon fruit. It was evident from inspection that the inoculation of a portion occurred during the preharvest drenching operations and/or in the packing line dump tank during the handling following the initial CA storage. Over 95% of the *Penicillium expansum* causing most of the decay was resistant to TBZ. The longer the storage (CA plus RA), the greater the percentage decay for fruit evaluated both before and after the 7-day ripening period.

CONCLUSIONS

CA storage followed by a line spray of 1750 p.p.m. ethoxyquin effectively controlled the development of SS for 5 months of CA storage plus

TABLE 3.
EFFECT OF LOCATION, PRESTORAGE DRENCH, STORAGE CONDITIONS AND MONTHS OF STORAGE ON CULLAGE AND DECAY IN "D'ANJOU" PEARS

Location	Prestorage ethoxyquin drench	Months storage		Percent culls	Percent rot and decay†				Percent total loss
		CA	Air		Post initial CA	Preripen	Postripen	Total	
OR	No	5	1	18.7 a	1.5 b	1.8 de	2.1 f	5.4 fg	24.1 fg
			2	18.7 a	1.5 b	3.2 de	3.1 ef	7.8 fg	26.5 efg
		7	1	18.7 a	1.5 b	2.0 de	3.9 ef	5.5 fg	26.2 fg
			2	18.7 a	1.5 b	3.9 de	6.5 de	11.9 fg	30.1 efg
	Yes	5	1	13.7 a	1.4 b	1.8 de	1.3 f	4.5 g	17.5 g
			2	13.7 a	1.4 b	1.1 e	4.6 ef	7.1 fg	20.8 g
		7	1	13.7 a	1.4 b	1.5 de	2.3 f	5.2 g	18.8 g
			2	13.7 a	1.4 b	2.7 de	4.2 ef	8.3 fg	21.0 g
WA	No	5	1	21.9 a	3.8 ab	3.5 de	6.4 de	13.7 ef	35.6 def
			2	21.9 a	3.8 ab	9.2 c	12.7 bc	25.7 cd	47.6 cd
		7	1	21.9 a	3.8 ab	15.1 b	10.6 c	29.4 cd	51.2 bc
			2	21.9 a	3.8 ab	21.4 a	16.0 b	41.8 ab	63.0 ab
	Yes	5	1	24.3 a	6.4 a	2.8 de	5.0 ef	14.2 ef	38.5 de
			2	24.3 a	6.4 a	5.2 d	9.8 cd	21.9 de	45.7 cd
		7	1	24.3 a	6.4 a	9.1 c	15.8 b	31.3 bc	55.6 acd
			2	24.3 a	6.4 a	14.7 b	21.2 a	42.3 a	66.3 a
Main effects – location									
OR	–	–	–	16.2 a	1.5 b	2.2 b	3.4 b	7.1 b	23.3 b
WA	–	–	–	23.1 a	5.1 a	10.1 a	12.2 a	27.4 a	50.5 a
Main effects – prestorage drench									
–	NO	–	–	20.3 a	2.6 a	7.5 a	7.6 a	17.8 a	38.1 a
–	Yes	–	–	19.0 a	3.9 a	4.8 a	8.0 a	16.7 a	35.7 b
Main effects – storage conditions									
–	–	5	1	19.7 a	3.3 a	2.3 d	3.7 c	9.3 c	29.0 c
–	–	5	2	19.7 a	3.3 a	4.7 c	7.6 b	15.4 b	35.1 b
–	–	7	1	19.7 a	3.3 a	6.9 b	8.1 b	18.3 b	38.0 b
–	–	7	2	19.7 a	3.3 a	10.7 a	11.8 a	25.8 a	45.4 a
Analysis of variance									
Location				ns	*	**	*	**	***
Drench				ns	ns	ns	ns	Ns	ns
L × D				ns	ns	ns	ns	Ns	ns
Storage				ns	ns	***	***	***	***
L × S				ns	ns	***	**	**	***
D × S				ns	ns	ns	ns	Ns	ns
L × D × S				ns	ns	ns	ns	Ns	ns

*, **, *** significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$, respectively.
† Means followed by the same letter within a column are not significantly different at $P = 0.05$.
ns, not significant.

1 month RA and 7 days of ripening. Fruit stored for less than 5 months in CA and sold within 1 month of release from CA would need only an application of 1750 p.p.m. ethoxyquin as compared with the current practice of 2750 p.p.m. This could result in a 36% reduction in the amount of ethoxyquin used. The addition of a 1000-p.p.m. ethoxyquin drench prior to CA storage extended the period of effective SS control to 2 months RA following 5 months CA storage, or to 1 month of RA following an additional 2 months of CA storage.

Minor amounts of PBC developed during storage. Utilization of 1% O_2 and 1% CO_2 in a flow-through system demonstrated that Oregon fruit could be safely stored under higher CO_2 conditions without the development of PBC. This demonstrates that Oregon fruit is no more sensitive to CO_2 injury than Washington fruit. This benefits the industry by reducing the costs of removing CO_2 from CA storage.

Growing location made little difference in the observed potential for fruit to develop scuffing injury when handled after 5 months of initial CA storage. Thus Washington growers can adopt the practices of most Oregon growers and store fruit in bulk containers for longer periods of time, and preserve their packaging options for several additional months.

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